

INDEX

- A** (*see* Magnetic vector potential)
- Acceleration:
 - due to gravity, 122
 - experienced by an electron, 74, 75
 - unit of, 521
- Addition of vectors, 2, 20
 - associative property of, 3
 - commutative property of, 2
 - parallelogram law of, 2
- Admittance:
 - characteristic, 443
 - input, 445
 - line, 443
- Air gap, 391, 393
- Aircraft, locating the position of, 517
- Allowed bands, 264, 265
- Ampere, 140
 - as unit of current, 522
- Ampere-turn, 393
- Ampere's circuital law, 154, 163, 173, 178
 - dilemma of, 210–213
- Ampere's circuital law in differential form, 162–163, 178
 - for surface current, 163
 - modified, 218
- Ampere's circuital law in integral form, 154–162, 178, 201
 - applications of, 159–162
 - modified, 210–217, 218
 - statement of, 156
- Ampere's law of force, 139–141, 178, 196
- Analogous source distributions, electric and magnetic fields for, 177, 179
- Analogy:
 - between electric and magnetic circuits, 390
 - between transmission-line and uniform plane wave parameters, 422
- Anisotropic conductors, 268
- Anisotropic dielectric materials, 281
- Anisotropic magnetic materials, 304
- Anode, 350
- Antenna, 497
 - directivity of, 500
 - half-wave dipole, 519
 - Hertzian dipole (*see* Hertzian dipole)

- Antenna (*contd.*)
 radiation intensity of, 499
 short dipole (*see* Short dipole)
- Antiferromagnetic material, 300
- Antiferromagnetism, 299, 300
- Apparent phase velocity, 418, 420
- Apparent wavelength, 417, 420
- Area as a vector, 13
- Array, 519
- Arrowhead, 1
- Associative property of vector addition, 3
- B**
- B** (*see* Magnetic flux density)
- B-H** curve, 316, 344
- Band:
 allowed, 264, 265
 forbidden, 264, 265
- Biot-Savart law, 142, 163, 211, 213, 214
 applications of, 143–149
- Bounce diagram, 428
- Bound electrons, 263, 275
- C**
- Candela, definition of, 522
- Capacitance:
 definition of, 376
 physical interpretation for, 377
 units of, 377
- Capacitance per unit length:
 for parallel wires, 381–383
 for some structures, 382
 general expression for, 380
 related to conductance per unit length, 380
 related to inductance per unit length, 381
- Capacitor: (*see also* Capacitance)
 electric stored energy in, 377
 quasistatic approximation for, 394, 397
 voltage-to-current relationship for, 395
- Cartesian coordinate system, 10–14
 arbitrary curve in, 13
 arbitrary surface in, 13
 coordinates for, 11, 18
 curl in, 54
 differential lengths, 13, 18
- Associative property (*contd.*)
 tion, 3
- Atom, classical model of, 263
- Atomic lattice, collisions with, 265
- Attenuation, 469
- Attenuation constant, 469
 for good conductor, 471
 for good dielectric, 470
 units of, 469
- Average macroscopic field, 279, 280, 302, 303
- Boundary condition:
 for normal component of **B**, 330
 for normal component of **D**, 329
 for normal component of **J**, 332
 for normal component of **P**, 333
 for tangential component of **E**, 330
 for tangential component of **H**, 331
- Boundary conditions, 327–336
 statements of, 329, 330, 331, 332
 summary of, 333
- Cartesian coordinate system (*contd.*)
 differential surfaces, 13, 18
 differential volume, 13, 18
 divergence in, 47
 gradient in, 33
 Laplacian of scalar in, 59
 Laplacian of vector in, 59
 limits of coordinates, 18
 orthogonal surfaces, 10, 18
 position vector, 14, 15
 unit vectors, 11, 18
- Cathode, 350
- Cavity resonator, 480
- Characteristic admittance, 443
- Characteristic impedance, 422
- Charge, 73
 conservation of, 74
 continuous distributions of, 82
 line, 82
 magnetic, 172, 203, 210
 of an electron, 73
 of a neutron, 73
 of a proton, 73
 surface, 82
 unit of, 74, 522

- Charge (*contd.*)
 volume, 82
- Charge density:
 line, 82
 surface, 82; *see also* Surface charge density
 volume, 82; *see also* Volume charge density
- Charge neutrality, in a dielectric, 283, 288
- Charges:
 conduction, 317
 polarization, 317
 true, 317
- Child–Langmuir law, 352
- Circuit:
 electric, 389
 distributed, 407
 magnetic, 389; *see also* Magnetic circuit
- Circuit theory, field basis of, 347
- Circuit law, Ampere's (*see* Ampere's circuital law)
- Circular current loop, 144
 dipole moment of, 147
 magnetic field due to, 144–147
- Circular polarization, 243
 left, 243
 right, 244
- Circulation, 41
 of \mathbf{H} compared to circulation of \mathbf{B} , 315
 per unit area, 49
- Closed path, line integral around (*see* Circulation)
- Closed surface integral, 39
- Coefficients, metric, 60
- Coercivity, 316
- Collisions, frictional mechanism due to, 265
- Communication, with underwater objects, 472
- Commutative property:
 of vector addition, 2
 of vector dot product, 4, 5
- Complete standing waves, 432
- Complex number, 234
- Complex power, 248
- Complex power density, 249
- Complex Poynting's theorem, 250, 325
- Complex Poynting vector, 248, 325
- Components of vectors, 9, 19–25
 relationships between, 23
- Conductance:
 definition of, 375
 physical interpretation for, 376
 units of, 375
 voltage-to-current relationship for, 397
- Conductance per unit length:
 for some structures, 382
 general expression for, 380
 related to capacitance per unit length, 380
- Conduction, 263–265
- Conduction current, compared to convection current, 267
- Conduction current density, 267
- Conduction currents, 134, 317
- Conduction electrons, 263
- Conductive dispersion, 470
- Conductivities:
 ranges of, 268
 table of, 269
- Conductivity, 268, 318
 definition of, 267
 of semiconductors, 268
 units of, 268
- Conductor:
 decay of charge placed inside, 270–271
 electric field at the boundary of, 272–274
 power dissipated in, 326–327, 376
 power dissipation density in, 322
 secondary electric field inside, 271, 272, 275
- Conductors, 263
 anisotropic, 268
 in electric fields, 269–275
 linear isotropic, 268
- Conservation of charge, 74
 law of, 215, 219
- Conservation of energy, 117
- Conservative field, 117

- Constant amplitude surfaces:
 - for radiation fields of Hertzian dipole, 495
 - in a parallel-plate waveguide, 459
- Constant of universal gravitation, 73
- Constant phase surfaces:
 - for radiation fields of Hertzian dipole, 495
 - for uniform plane wave, 414, 417
 - in parallel-plate waveguide, 459
- Constant VSWR circle, 450
- Constitutive relations, 72, 262, 318, 347
- Continuity equation, 220, 244, 317, 318
 - in integral form, 320, 321, 328
 - in phasor form, 245
- Continuous distributions of charge, 82
- Convection current, compared to conduction current, 267
- Convection currents, 134, 317
- Coordinate system:
 - cartesian, 10–14
 - cylindrical, 14–16
 - left hand, 11, 15, 17
 - parabolic cylindrical, 62
 - right hand, 11, 15, 17
 - spherical, 16–18
- Coordinates:
 - cartesian, 11, 18
 - cylindrical, 15, 18
 - limits of, 18
 - relationship between, 19
 - spherical, 16, 18
- Coulomb, 75
 - as unit of charge, 74
- Coulomb field, 77
- Coulomb potential, 107
- Coulomb's law, 75–76, 139, 178, 193, 196
- Cross product of vectors, 5, 20, 60
 - defining unit vector by, 7
 - differentiation of, 32
 - distributive property of, 6
- Crystalline solid, 263
- Curie temperature, 299
- Curl, 48–58
 - definition of, 48
- Curl (*contd.*)
 - divergence of, 56
 - in cartesian coordinates, 54
 - in cylindrical coordinates, 54
 - in general coordinates, 61
 - in spherical coordinates, 53
 - of curl of a vector, 59
 - of gradient of a scalar, 56
 - physical significance of, 54–56
- Curl meter, 54
- Current:
 - conduction, 267
 - convection, 267
 - displacement, 215, 295
 - filamentary, 141
- Current density:
 - conduction, 267
 - displacement, 219, 295
 - relation to charge density, 137–138
 - surface, 149; *see also* Surface current density
 - volume, 149; *see also* Volume current density
- Current element:
 - magnetic field of, 142, 178
 - magnetic force on, 137–139
- Current enclosed by closed path, uniqueness of, 157–158, 210, 211
- Current loop:
 - dipole moment of, 169
 - vector potential at large distances, 167–169
- Current sheet, magnetic field due to, 149–151
- Current transmission coefficient, 426
- Currents:
 - conduction, 134, 317
 - convection, 134, 317
 - magnetization, 134, 317
 - polarization, 134, 317
 - true, 317
- Cutoff frequency, 458
- Cutoff wavelength, 457–458
- Cycloid, 196
- Cylindrical coordinate system, 14–16
 - coordinates for, 15, 18
 - curl in, 54

- Cylindrical coordinate system (*contd.*)
 differential lengths, 16, 18
 differential surfaces, 16, 18
 differential volume, 16, 18
 divergence in, 46
 gradient in, 36
 Laplacian of scalar in, 59
- D**
- D** (*see* Displacement flux density)
 Degree Kelvin, definition of, 522
 Del operator, 32
 Delta function, Dirac (*see* Dirac delta function)
 Density:
 charge (*see* Charge density)
 current (*see* Current density)
 Depth, skin, 472
 Depth of penetration, 472
 Diagram:
 dispersion, 466
 Γ -plane, 437
 ω - β_{zn} , 466
 Diamagnetic effect, 296
 illustration of, 297–298
 Diamagnetic materials, 296, 300
 values of χ_m for, 304
 Diamagnetism, 296, 299
 Dielectric, 265
 charge neutrality in, 283, 288
 electric stored energy density in, 322–323
 polarization energy density in, 323
 Dielectric constant, 291
 Dielectrics, 263
 anisotropic, 281
 effects of polarization in, 281–289
 linear isotropic, 281
 polarization in, 275–278
 secondary fields in, 281, 283, 289
 table of relative permittivities for, 292
 Differential lengths:
 in cartesian coordinates, 13, 18
 in cylindrical coordinates, 16, 18
 in spherical coordinates, 17, 18
 Differential surfaces:
 in cartesian coordinates, 13, 18
 in cylindrical coordinates, 16, 18
 Cylindrical coordinate system (*contd.*)
 Laplacian of vector in, 60
 limits of coordinates, 18
 orthogonal surfaces, 14, 18
 position vector, 16
 unit vectors, 15, 18
 Differential surfaces (*contd.*)
 in spherical coordinates, 17, 18
 Differential volume:
 in cartesian coordinates, 13, 18
 in cylindrical coordinates, 16, 18
 in spherical coordinates, 17, 18
 Differentiation of vectors, 29–32
 Dimensions, 522, 526
 table of, 523–526
 Diode, vacuum, 350
 Dipole:
 electric (*see* Electric dipole)
 half-wave, 519
 Hertzian (*see* Hertzian dipole)
 magnetic (*see* Magnetic dipole)
 short (*see* Short dipole)
 Dipole antenna (*see* Dipole)
 Dipole layer, electric, 349
 Dipole moment:
 electric (*see* Electric dipole moment)
 magnetic (*see* Magnetic dipole moment)
 of circular loop of current, 147
 of current loop, 169
 per unit volume, 278, 301
 Dipole moment per unit volume:
 electric, 278
 magnetic, 301
 Dirac delta function, 102, 103, 163
 three-dimensional, 133
 Direction lines, 29, 90–92, 108, 109, 119
 for electric dipole field, 91–92
 for infinite line charge, 115
 of **D** compared to direction lines of **E**, 292, 293, 295
 of **P**, 295
 Directivity:
 definition of, 500

- Directivity (*contd.*)
 of Hertzian dipole, 500
 of short dipole, 500
- Dispersion, 463
 conductive, 470
 geometric, 468
 parametric, 485
- Dispersion diagram, 466
- Displacement, 295
- Displacement current, 215, 295
 consequence of, 216
- Displacement current density, 219, 295
- Displacement flux, 295
- Displacement flux density, 290, 295
 definition of, 290
 relationship with \mathbf{E} , 290, 291, 318
 units of, 290
- Distributed circuit:
 concept, 407
 representation of transmission line
- E**
- \mathbf{E} (*see* Electric field intensity)
- Earth, gravitational field of, 73
- Effective permittivity, of a plasma medium, 485
- Electrets, 276
- Electric dipole, 80
 analogy with magnetic dipole, 47
 direction lines for the field of, 91–92
 electric field of, 80–83
 equipotential surfaces for, 109–110
 potential field of, 109
 schematic representation of, 276
 two-dimensional, 118, 125
- Electric dipole layer, 349
- Electric dipole moment:
 definition of, 82
 due to electronic polarization, 276–278
- Electric energy:
 for spherical volume charge, 225
 stored in a capacitor, 377
 stored in a resonator, 479
- Electric energy density:
 in a dielectric, 323, 377
- Distributed circuit (*contd.*)
 by, 406
- Distributive property:
 of vector cross product, 6
 of vector dot product, 5
- Divergence, 44–48
 definition of, 44
 in cartesian coordinates, 47
 in cylindrical coordinates, 46
 in general coordinates, 61
 in spherical coordinates, 47
 of curl of a vector, 56
 of gradient of a scalar, 59
- Divergence theorem, 47–48
- Division of vector by a scalar, 3, 20
- Domains, magnetic, 299
- Dominant mode, 459
- Dot product of vectors, 4, 20, 60
 commutative property of, 4, 5
 differentiation of, 32
 distributive property of, 5
- Drift velocity, 265, 266, 267
- Electric energy density (*contd.*)
 in free space, 225
 time-average, 249, 323
- Electric field (*see also* Electric field intensity)
 as viewed by a moving observer, 206, 207
 at the surface of a conductor, 273
 concept, 73–75, 193
 energy density in, 225, 324
 energy storage in, 221–225
 induced, 198, 199, 201
- Electric field flux, 93–96, 212
 evaluation of, 96–97
- Electric field intensity:
 definition of, 74, 135
 due to dipole, 80–83
 due to infinite line charge, 83–85, 97–99, 177, 179
 due to infinite sheet charge, 85–86, 99–100, 179
 due to line charge, 89, 178
 due to point charge, 77, 79, 178
 due to point charges, 77–78, 79–80
 due to spherical volume charge,

- Electric field intensity (*contd.*)
 87–89, 100–101, 348–350
 due to surface charge, 89, 178
 due to volume charge, 89, 178
 from V , 120, 178
 unit of, 74
- Electric force:
 as viewed by a moving observer, 207
 between two point charges, 75, 76
 on a test charge, 74
- Electric polarization (*see* Polarization in dielectrics)
- Electric scalar potential (*see also* Potential field)
 due to a time-varying point charge, 491
 due to a time-varying volume charge, 492
 time-varying, 202
- Electric susceptibility, 281
- Electromagnetic energy transmission, 405
- Electromagnetic field, 72, 193
 power flow in, 230–234
- Electromagnetic field laws, summary of, 251, 252
- Electromagnetic wave propagation, 252, 408; *see also* Wave propagation
- Electromagnetic waves, 347, 412
 radiation of, 489–500
- Electromotance, 197
- Electromotive force, 197
- Electron, 73
 charge of, 73
 mass of, 73
 mobility of, 266, 267
- Electron cloud, 263, 264
- Electron drift, 263
- Electron spin, 296
- Electronic polarizability, 278
- Electronic polarization, 275
 illustration of, 276–278
- Electrons:
 bound, 263
 conduction, 263
 free, 263
- Electrostatic field (*see* Static electric field)
- Electrostatic potential (*see also* Potential field)
 for line charge, 115, 178
 for surface charge, 115, 178
 for volume charge, 115, 178
 from Laplace's equation, 353–369
 from Poisson's equation, 348–350
- Elliptical polarization, 243
- Empty energy levels, 265
- Energy:
 electric (*see* Electric energy)
 kinetic, 135, 322
 magnetic (*see* Magnetic energy)
 potential (*see* Potential energy)
 unit of, 522
- Energy band, 264
- Energy density:
 in electric field, 225, 323
 in magnetic field, 229, 324
 magnetization, 324
 polarization, 323
- Energy levels, 263–265
- Energy storage:
 in electric field, 221–225
 in magnetic field, 226–230
 in parallel-plate resonator, 477–483
- Equality of vectors, 1, 20
- Equation, continuity (*see* Continuity equation)
- Equations, Maxwell's (*see* Maxwell's equations)
- Equipotential surfaces, 107, 108, 109, 119
 for electric dipole, 109–110
 for infinite line charge, 115
 for point charge, 107–108
- Equivalent circuit representation:
 for input behavior beyond quasistatic approximation, 400–401
 for magnetic circuit, 391–393
 for transmission-line equations, 405–407
- External inductance, 383
- Extrinsic semiconductor, 265

- F**
- Fabry-Perot resonator, 481–483
 - Farad, 377
 - Faraday, 193, 196, 215
 - Faraday's law, 197
 - Faraday's law in differential form, 203–210
 - statement of, 204
 - Faraday's law in integral form, 196–203
 - applications of, 198–201
 - consequences of, 202
 - statement of, 197
 - Feedback loop, 282, 305
 - Fermi level, 264, 265
 - Ferrimagnetic material, 300
 - Ferrimagnetism, 299, 300
 - Ferrites, 300
 - Ferroelectric materials, 276
 - Ferromagnetic materials, 299, 300
 - Ferromagnetism, 299, 300
 - theory of, 299–300
 - Field:
 - definition of, 25
 - electric (*see* Electric field)
 - gravitational, 73
 - local, 279, 301
 - magnetic (*see* Magnetic field)
 - magnetizing, 301, 303
 - polarizing, 276, 279
 - Field intensity:
 - electric (*see* Electric field intensity)
 - gravitational, 73
 - magnetic (*see* Magnetic field intensity)
 - Field points, 89
 - Field vectors:
 - fundamental, 317
 - mixed, 318
 - Fields:
 - conservative, 117
 - irrotational, 118
 - quasistatic, 394
 - radiation, 495
 - scalar, 25–27
 - solenoidal, 173
 - static, 72
 - time-varying, 72
 - Fields (*contd.*)
 - vector, 27–29
 - Filamentary current:
 - magnetic field due to, 142
 - magnetic force on, 138
 - Flux:
 - displacement, 295
 - magnetic, 172
 - of **D** compared to flux of **E**, 295
 - of electric field, 93–96
 - of a vector quantity, 37
 - per unit volume, 44
 - Flux density:
 - displacement (*see* Displacement flux density)
 - magnetic (*see* Magnetic flux density)
 - Flux lines, 90
 - Flux linkage, 378
 - Forbidden band, 264, 265
 - Force:
 - Ampere's law of, 139–141
 - electric (*see* Electric force)
 - gravitational, 139
 - Lorentz, 194
 - magnetic (*see* Magnetic force)
 - unit of, 522
 - Force equation, Lorentz, 193, 194
 - Force per unit volume, 194
 - Fourier series, 365
 - Free electrons, 263
 - Free space:
 - intrinsic impedance of, 412
 - permeability of, 140
 - permittivity of, 76, 140
 - velocity of light in, 140
 - Frequency, 413
 - cutoff, 458
 - plasma, 485
 - Frequencies of oscillation, natural, 434
 - Function:
 - scalar, 25
 - vector, 27
 - Fundamental frequency of oscillation, 434
 - Fundamental mode, 434

G

- Gap, air, 391, 393
- Gauss' law, 154, 163, 178, 214, 215
- Gauss' law in differential form, 101–103, 163, 178
 - for sheet charge, 103–104
 - statement of, 102
- Gauss' law in integral form, 92–101, 178, 273
 - applications of, 97–101
 - statement of, 96
- Gaussian surface, 97, 98, 99, 100
- Geometric dispersion, 468
- Good conductor, 319
 - attenuation constant, 471
 - intrinsic impedance for, 471
 - Maxwell's equations for, 321
 - phase constant, 471
 - skin effect in, 473
- Good dielectric, 319
 - attenuation constant, 470
 - intrinsic impedance for, 470
 - phase constant, 470

H

- H** (*see* Magnetic field intensity)
- Henry, 378
- Hertzian dipole:
 - directivity of, 500
 - electromagnetic fields for, 494–495
 - normalized radiation intensity for, 500
 - radiation fields for, 495
 - radiation intensity for, 500
 - radiation resistance for, 497
 - retarded potentials for, 493–494

I

- Identities:
 - involving curl, 56
 - vector, 61–62
- Image charge:
 - for line charge near cylindrical conductor, 371–373
 - for point charge near plane conductor, 370–371
 - for point charge near spherical conductor, 373, 503
- Images, method of, 370–373
- Imaginary part, 237

- Gradient, 32–36
 - curl of, 56
 - definition of, 32
 - in cartesian coordinates, 33
 - in cylindrical coordinates, 36
 - in general coordinates, 61
 - in spherical coordinates, 36
 - physical significance of, 33
- Gravitation, constant of universal, 73
- Gravitational field, 73, 75, 103–105, 117
- Gravitational field intensity, 73
- Gravitational force, 139
- Gravity, acceleration due to, 122
- Ground, 295
- Grounded conductor, 293, 370, 371
- Group velocity, 463–468
 - concept of, 463–465
 - in a parallel-plate waveguide, 465–467
 - in a plasma medium, 486
 - physical interpretation for, 467
- Guide impedance, 459
- Guide wavelength, 458

- Hertzian dipole (*contd.*)
 - time-average radiated power, 496
- Holes, 263, 265
 - mobility of, 267
- Hysteresis, 300, 315
- Hysteresis curve, 316
- Hysteresis curves, characteristics of, 316
- Hysteresis effect, development of, 316
- Hysteresis loop, 316

- Impedance:
 - characteristic, 422
 - guide, 459
 - input, 434
 - internal, 474
 - line, 434, 436
 - normalized, 445
 - wave, 434, 436
- Impedance matching:
 - by quarter wave transformer, 442
 - by stub (*see* Stub matching)

- Imperfect conductor (*see* Good conductor)
 Imperfect dielectric (*see* Good dielectric)
 Impulse function (*see* Dirac delta function)
 Incident wave, 425
 Induced electric field, 198, 199, 201
 solenoidal character of, 201
 Induced voltage, 197
 Inductance (*see also* Inductor)
 definition of, 378
 external, 383
 internal, 383
 mutual, 386
 physical interpretation for, 378
 self, 385
 units of, 378
 Inductance per unit length:
 for some structures, 382
 general expression for, 380
 related to capacitance per unit length, 381
 Inductor (*see also* Inductance)
 condition for quasistatic approximation for, 395, 397
 magnetic energy stored in, 382
 voltage-to-current relationship for, 396
 Inhomogeneous wave equations, 490
 Input admittance, of short-circuited line, 445
 Input behavior:
 beyond quasistatic approximation, 400–402
 under quasistatic approximation, 397–400
 Input impedance, of short-circuited line, 434
 Input reactance, of short-circuited line, 435
 Input susceptance, 453
 Insulators, 263
- J** **J** (*see* Volume current density)
- K** Kelvin degree, definition of, 522
 Kilogram, definition of, 521
 Kinetic energy, 135, 322
- Integral:
 closed line (*see* Circulation)
 closed surface, 39
 line, 40–43
 surface, 37–40
 volume, 36–37
 Integration of vectors, 43
 Intensity:
 electric field (*see* Electric field intensity)
 gravitational field, 73
 magnetic field (*see* Magnetic field intensity)
 radiation (*see* Radiation intensity)
 Internal impedance, 474
 application of, 477
 for hollow cylindrical conductor, 475
 Internal inductance:
 definition of, 383
 general expression for, 385
 Internal inductance per unit length, 383
 computation of, 383–385
 International system of units, 521
 Intrinsic impedance:
 definition of, 411–412
 for good conductor, 471
 for good dielectric, 470
 for perfect dielectric, 411
 units of, 412
 Intrinsic semiconductor, 265
 Ionic polarization, 276
 Ionosphere, 486
 condition for reflection of wave, 488
 description of, 486
 path of wave in, 486–489
 Irrotational fields, 118
 Isotropic conductors, linear, 268
 Isotropic magnetic materials, 304
 Iteration, 369
- Joule, definition of, 522
 Kirchoff's current law, 406
 Kirchoff's voltage law, 406

L

- Laplace's equation:
 applications of, 353–369
 for electrostatic potential, 120, 348, 353
 for magnetic vector potential, 171
 in two dimensions, 359
 numerical solution of, 367–369
 solution of, 353, 359–360
 solution of steady current problems, 365–367
- Laplace's equations, solutions for one-dimensional cases, 356
- Laplacian of a scalar, 59
 in cartesian coordinates, 59
 in cylindrical coordinates, 59
 in general coordinates, 61
 in spherical coordinates, 59
- Laplacian of a vector, 59–60
 in cartesian coordinates, 59
 in cylindrical coordinates, 60
 in spherical coordinates, 60
- Laser oscillation, 481–483
- Lattice, atomic, 265
- Law of conservation of charge, 215, 219
 in differential form, 220
- Law of reflection, in optics, 455
- Leakage, of magnetic flux, 388
- Left hand coordinate system, 11, 15, 17
- Lenz's law, 198, 298
- Level, Fermi, 264, 265
- Light, velocity of (*see* Velocity of light)
- Line admittance, 443
 from the Smith chart, 448–452
- Line charge, 82

M

- M (*see* Magnetization vector)
- m** (*see* Magnetic dipole moment)
- Macroscopic field, average, 279, 280, 302, 303
- Macroscopic scale observations, 262
- Magnetic charge, 172, 203, 210
- Magnetic circuit, 389
 analogy with electric circuit, 390
 analysis of, 391–393
 equivalent circuit representation for,

- Line charge (*contd.*)
 electric field of, 89, 178
 infinitely long, 83
 potential field of, 115, 178
- Line charge density, 82
 units of, 82
- Line current:
 magnetic field due to, 142–143, 178
 magnetic vector potential due to, 164, 178
- Line impedance:
 for general case, 436
 for short-circuited line, 434
 from the Smith chart, 448–451
- Line integral, 40–43, 105
 around closed path, 41
 evaluation of, 42–43
 to surface integral, 58
- Linear isotropic conductors, 268
- Linear isotropic dielectrics, 281
- Linear polarization, 243
- Linear quadrupole, 122
- Lines:
 direction (*see* Direction lines)
 transmission — (*see* Transmission lines)
- Linkage, flux, 378
- Local field, 279, 301
- Loop, current (*see* Current loop)
- Lorentz condition, 490
- Lorentz force, 194
- Lorentz force equation, 72, 193, 194, 230, 317
- Lossy media, 468
- Lossy transmission line, 475–477
- Low-frequency circuit theory, field basis of, 393–402

- Magnetic circuit (*contd.*)
 391
- Magnetic dipole, 144
 magnetic field of, 144–147
 oscillating, 518
 schematic representation of, 296
 two-dimensional, 173, 185
- Magnetic dipole moment:
 definition of, 147
 diamagnetic effect on, 297–298

- Magnetic dipole moment (*contd.*)
 of plane loop of wire, 169
- Magnetic domain, 299
- Magnetic energy:
 for cylindrical surface current, 229–230
 in a nonlinear magnetic material, 324
 stored in an inductor, 378
 stored in a resonator, 479
- Magnetic energy density:
 in free space, 229
 in a magnetic material, 324, 378
 time-average, 249, 324
- Magnetic field (*see also* Magnetic flux density)
 concept, 135–136, 193
 energy density in, 229, 324
 energy storage in, 226–230
 realizability of, 172–173
- Magnetic field intensity, 312
 definition of, 312
 relationship with **B**, 312, 318
 units of, 312
- Magnetic flux, 172, 196, 197
- Magnetic flux density:
 definition of, 135–136, 178
 due to current element, 142, 178
 due to cylinder of current, 151–154, 161–162
 due to finitely long wire, 144, 177, 179
 due to infinite sheet of current, 149–151, 159–161, 179
 due to infinitely long solenoid, 147–149, 173–177
 due to infinitely long wire, 144, 177, 179
 due to line current, 142–143, 178
 due to magnetic dipole, 144–147
 due to surface current, 178
 due to volume current, 178
 from **A**, 164, 178
 units of, 136
- Magnetic force:
 between two current elements, 140
 between two current loops, 139–141
 in terms of current, 138
- Magnetic force (*contd.*)
 on a closed loop of wire, 139
 on filamentary wire, 138
 on a moving charge, 135
- Magnetic materials, 296
 anisotropic, 304
 effects of magnetization in, 305–310
 isotropic, 304
 magnetization of, 296–301
 secondary fields in, 305, 307, 310
- Magnetic polarizability, 301
- Magnetic quadrupole, 186
- Magnetic scalar potential, 356, 357
- Magnetic susceptibility, definition of 304
- Magnetic susceptibilities, table of values of, 304
- Magnetic vector potential, 163–172, 177
 due to loop of wire, 167–169
 due to time-varying current, 492
 for Hertzian dipole, 494
 for infinitely long wire, 165–166
 for line current, 164, 178
 for surface current, 164, 178
 for volume current, 164, 178
 Laplace's equation for, 171
 Poisson's equation for, 171
- Magnetization, 296
- Magnetization current, 134, 317
- Magnetization currents, compared to true currents, 317
- Magnetization energy density, 324
- Magnetization surface current, 306, 310
- Magnetization surface current density, 308
 in terms of magnetization vector, 310
- Magnetization vector:
 definition of, 301
 relationship with **B**, 304
 units of, 301
- Magnetization volume current, 307, 310
- Magnetization volume current density, 308

- Magnetization volume current density
(*contd.*)
in terms of magnetization vector,
310
- Magnetizing field, 301, 303
- Magnitude of vector, 1, 20
- Mass, 73
of an electron, 73
of a neutron, 73
of a proton, 73
- Mass spectrograph, 180
- Matching:
between two dielectric media, 441–
442
by quarter wave transformer, 442
in a waveguide, 460–462
stub (*see* Stub matching)
transmission-line (*see* Transmission-
line matching)
- Materials:
antiferromagnetic, 300
conductive (*see* Conductors)
constitutive relations for, 318
diamagnetic (*see* Diamagnetic mate-
rials)
dielectric (*see* Dielectrics)
ferrimagnetic, 300
ferroelectric, 276
ferromagnetic, 299, 300
magnetic (*see* Magnetic materials)
Maxwell's equations for, 317–321
nonmagnetic, 263
paramagnetic (*see* Paramagnetic
materials)
power and energy in, 321–325
- Maxwell, 193, 214, 215, 295
- Maxwell's equations, 72, 347
applications of, 348–500
for good conductors, 321
for perfect dielectrics, 320, 321, 408
for static fields, 178, 318, 320–321
for time-varying fields, 244, 252,
317, 320–321
- Natural frequencies of oscillation, 434
- Natural modes of oscillation, 434
- Neper, 469
- Neutron, 73
- Maxwell's equations (*contd.*)
in integral form, 320–321, 328
in phasor form, 244–245, 251, 319
independence of, 317
summary of, 317–321
table of, 320–321
- Meter, definition of, 521
- Method of images, 370
application of, 370–373
- Metric coefficients, 60
- Mho, 375
- Microscopic scale observations, 262
- MKS rationalized units, 76, 521
- Mobility, 266, 267
units of, 267
- Mode, 458
dominant, 459
- Modes:
TE, 458
TM, 463
- Modes of oscillation, natural, 434
- Modified Ampere's circuital law:
in differential form, 218
in integral form, 210–217, 218
- Molecular polarizability, 278
- Molecule:
nonpolar, 275
polar, 275
- Moment:
electric dipole (*see* Electric dipole
moment)
magnetic dipole (*see* Magnetic dipole
moment)
- Moving charge, magnetic force on,
135
- Moving observer, electric field viewed
by, 206, 207
- Multiplication of vector, by a scalar, 3,
20
- Multipole, 82
- Mutual inductance:
computation of, 386–387
definition of, 386
- Neutron (*contd.*)
charge of, 73
mass of, 73
- Newton, definition of, 521

- Newton's third law, 141, 182
 Nonmagnetic materials, classification of, 319
 Nonpolar molecule, 275
 Normal component of **B**, boundary condition for, 330
 Normal component of **D**, boundary condition for, 329
 Normal component of **J**, boundary condition for, 332
 Normal component of **P**, boundary condition for, 333
 Normal vector to a surface:
 from cross product, 33–35
- O**
- Observations:
 macroscopic scale, 262
 microscopic scale, 262
 Observer:
 moving, 206, 207
 stationary, 206
 Occupied levels, 264–265
 Ohm, 375
 Ohm's law, 268, 375
 ω - β_z diagram, 466
- P**
- P** (*see* Polarization vector, Poynting vector)
p (*see* Electric dipole moment)
 Paddle wheel, 54, 118
 Parabolic cylindrical coordinate system, 62
 Parallel conductor structures:
 capacitance per unit length, 378–380
 conductance per unit length, 378–380
 inductance per unit length, 378–380
 Parallel-plate resonator, 477–483
 energy storage in, 478–479
 Q factor for, 480–481
 resonant frequencies for, 480
 Parallel-plate waveguide, 456
 constant amplitude surfaces, 459
 constant phase surfaces, 459
 cutoff frequencies for, 458
 cutoff wavelengths for, 458
 group velocity in, 467
 guide wavelength, 458
 Normal vector to a surface (*contd.*)
 from gradient, 33–35
 Normalized line admittance, 451–453
 Normalized line impedance, 445, 451–453
 definition of, 445
 Normalized radiation intensity, 500
 Notation:
 source point—field point, 89
 transmission-line waves, 423
 vector, 1
 Nuclear spin, 296
 Nucleus, 263
- Operation, Laplacian, 59
 Operator, del, 32
 Optical frequencies, 481
 Orbit, electronic, 297–298
 Orientational polarization, 276, 299
 Origin, 11
 Orthogonality property, of sine functions, 364
 Oscillation, laser, 481–483
- Parallel-plate waveguide (*contd.*)
 $TE_{m,0}$ modes, 458
 TE waves in, 456
 time-average power flow in, 459
 Parallelepiped, 7
 Parallelogram law:
 of vector addition, 2
 of vector subtraction, 3
 Paramagnetic materials, 299, 300
 values of χ_m for, 304
 Paramagnetism, 299
 Parametric dispersion, 485
 Partial derivatives, of unit vectors, 31
 Partial standing waves, 436
 patterns for, 436–439
 VSWR for, 438
 Path, closed (*see* Closed path)
 Pauli's exclusion principle, 264
 Penetration, depth of, 472
 Perfect conductor, 319
 boundary conditions, 333, 334–336
 normal incidence of uniform plane

- Perfect conductor (*contd.*)
 waves on, 430
 oblique incidence of uniform plane
 waves on, 454–456
- Perfect dielectric, 319
 boundary conditions, 333
 intrinsic impedance, 411
 Maxwell's equations for, 320
 phase constant, 414
 velocity of propagation, 411
- Permanent magnetization, problems in-
 volving, 356–359
- Permeability, 313, 318
 definition of, 313
 of free space, 140
 of magnetic material, 313
 relative, 312
 units of, 140
- Permittivity, 291, 318
 definition of, 291
 of dielectric material, 291
 of free space, 76, 140
 relative, 291
 units of, 76
- Phase, 414
- Phase angle, 234
- Phase constant, 414, 469
 for good conductor, 471
 for good dielectric, 470
 for perfect dielectric, 414
 for plasma, 485
 units of, 415
- Phase refractive index, 488
- Phase velocity, 414
 apparent, 418
- Phasor, 234
 graphical representation of, 234,
 235
- Phasor form:
 continuity equation in, 245
 Maxwell's equations in, 244–245,
 251, 319
- Phasor technique, 235–242
 extension to vector quantities, 239–
 242
 illustration of, 235–239
- Phasors, differences and similarities
 with vectors, 239–242
- Plane wave, uniform (*see* Uniform
 plane wave)
- Plasma:
 description of, 484
 effective permittivity of, 485
 example of, 486
 phase constant, 485
 wave propagation in, 484–489
- Plasma frequency, definition of, 485
- Point charge:
 electric field of, 77, 79, 178
 equipotential surfaces for, 107, 108
 potential field of, 107, 109–111,
 178
- Point charges:
 electric field of, 77–78, 79–80
 potential field of, 108, 111–112
- Poisson's equation:
 applications of, 348–352
 for electrostatic potential, 120, 348
 for magnetic vector potential, 171
- Polar molecule, 275
- Polarizability:
 electronic, 278
 magnetic, 301
 molecular, 278
- Polarization in dielectrics, 263, 275
 electronic, 275, 276–278
 ionic, 276
 orientational, 276
- Polarization of vector fields, 242–244,
 420–421
 circular, 243
 elliptical, 243
 left-circular, 243
 linear, 243
 right-circular, 244
- Polarization charges, compared to true
 charges, 317
- Polarization current, 134, 285, 288,
 289, 317
- Polarization current density, 285
 in terms of polarization vector, 288
- Polarization currents, compared to true
 currents, 317
- Polarization energy density, 323
- Polarization surface charge, 283, 284,
 287, 288, 289

- Polarization surface charge density, 284, 286
 in terms of polarization vector, 288
- Polarization vector:
 definition of, 278
 relationship with \mathbf{E} , 281
 units of, 278
- Polarization volume charge, 284, 287, 288, 289
- Polarization volume charge density, 286
 in terms of polarization vector, 288
- Polarizing field, 276, 279
- Position vector:
 in cartesian coordinates, 13–14
 in cylindrical coordinates, 16
 in spherical coordinates, 17–18
- Potential, 106, 107
 electric scalar (*see* Electric scalar potential)
 electrostatic (*see* Potential field)
 magnetic scalar, 356, 357
 magnetic vector (*see* Magnetic vector potential)
 time varying scalar, 210; *see also* Electric scalar potential
 time varying vector, 210; *see also* Magnetic vector potential
- Potential difference, 103–105, 202, 221
 compared to voltage, 202
 units of, 105, 522
- Potential energy, 103, 105, 119, 155, 228
 of continuous charge distribution, 223, 224
 of solenoidal current distribution, 226–228
 of system of point charges, 222
- Potential field:
 at large distances, 109–112
 of electric dipole, 109
 of infinite line charge, 113–115
 of line charge, 115, 178
 of point charge, 107, 109–111, 178
 of point charges, 108, 111–112
 of spherical volume charge, 348–350
 of surface charge, 115, 178
- Potential field (*contd.*)
 of volume charge, 115, 178
- Potentials:
 differential equations for, 178
 for Hertzian dipole, 492–494
 retarded, 492
 wave equations for, 490
- Power:
 associated with movement of charge, 230–231
 dissipated in a conductor, 322, 376
 radiated by an antenna, 233–234
 time-average, 250
 unit of, 522
- Power balance, at junction of transmission lines, 426
- Power density:
 associated with electromagnetic field, 232
 complex, 249
 time-average, 249
- Power dissipation density, in a conductor, 322, 376
- Power flow:
 along a transmission line, 407, 442
 for a parallel-plate waveguide, 456
 in an electromagnetic field, 230–234
 into a good conductor, 473–474
- Poynting, 232
- Poynting theorem, 232
 complex, 250, 325
- Poynting vector, 232, 246, 247
 complex, 248, 325
 for material medium, 325
 interpretation, 232
 surface integral of, 232, 247
 time-average, 248
 units of, 232
- Product:
 cross (*see* Cross product of vectors)
 dot (*see* Dot product of vectors)
 scalar (*see* Dot product of vectors)
 vector (*see* Cross product of vectors)
- Projection of vectors, 9
- Propagation:
 electromagnetic wave, 252, 408; *see*

Propagation (*contd.*)
 also Wave propagation
 velocity of (*see* Velocity of propagation)

Propagation constant:
 for lossy medium, 469

Q

Q factor:
 definition of, 480
 for parallel-plate resonator, 480–481

Quadrupole, 82, 109, 111, 112
 linear electric, 122
 magnetic, 186
 oscillating electric, 518
 rectangular electric, 129

Quality factor (*see Q* factor)

Quantum theory, 263

Quarter wave transformer, 442

R

Radiation, 489–500

Radiation fields:
 for Hertzian dipole, 495
 for short dipole, 499

Radiation intensity:
 definition of, 499–500
 for Hertzian dipole, 500
 normalized, 500

Radiation resistance:
 definition of, 497
 for Hertzian dipole, 497
 for short dipole, 499

Rationalized MKS units, 76, 521

Reactance, input (*see* Input reactance)

Real part, 237

Rectangular coordinate system (*see* Cartesian coordinate system)

Rectangular waveguide, 462
 TE modes in, 462
 TM modes in, 463

Reference point, 107, 113, 114

Reference potential, 107

Reflected wave, 425

Reflection coefficient:
 current, 426
 from the Smith chart, 448–449
 generalized, 436

Propagation constant (*contd.*)
 for plasma, 485

Propagation vector, 416

Proton, 73
 charge of, 73
 mass of, 73

Quarter wave transformer (*contd.*)
 in a waveguide, 460–462

Quasistatic approximation:
 behavior for frequencies beyond, 400–402
 for a capacitor, 394, 397
 for an inductor, 395, 397
 for a resistor, 397
 method of finding condition for, 397–400

Quasistatic fields, 394

Quasistatics, 393–402

Reflection coefficient (*contd.*)
 voltage, 426

Reflection condition, for incidence on ionosphere, 488

Refractive index, phase, 488

Relative permeability, 312
 for ferromagnetic materials, 315, 316
 incremental, 316

Relative permittivity, 291
 table of values of, 292

Reluctance, definition of, 390

Remanence, 316

Resistance:
 definition of, 375
 radiation (*see* Radiation resistance)
 voltage-to-current relationship for, 397
 units of, 375

Resistor (*see also* Resistance)
 quasistatic approximation for, 397

Resonance, 479

Resonant frequencies, for parallel-plate resonator, 480

Resonator:
 cavity, 480
 Fabry–Perot, 481–483

Resonator (*contd.*)

parallel-plate, 477–483

 Q of, 480

Retarded potentials, 492

for Hertzian dipole, 493–494

Retentivity, 316

S

Scalar:

definition of, 1

gradient of, 32

Laplacian of, 59

Scalar fields, 25–27

graphical representation of, 26

Scalar function, 25

rate of increase of, 32, 36

Scalar potential:

electric (*see* Electric scalar potential)magnetic (*see* Magnetic scalar potential)Scalar product (*see* Dot product of vectors)

Scalar triple product, 7, 21

Scalar wave equation, one-dimensional, 409

Scalars, examples of, 1

Second, definition of, 521

Secondary fields, 281, 289, 305, 310, 311

Self inductance, 385

Semiconductors, 263, 265, 267

conductivity of, 268

extrinsic, 265

intrinsic, 265

Separation of variables technique, 359–360

Sheet charge, 83, 99, 102, 103

Shielding, 473

Short-circuited line:

input impedance of, 434–435

standing wave patterns for, 433

voltage and current on, 430–433

Short dipole:

current distribution along, 497, 498

directivity for, 500

normalized radiation intensity for, 500

radiation fields for, 499

Right-hand coordinate system:

cartesian, 11

cylindrical, 15

spherical, 17

Ring charge, 123

Short dipole (*contd.*)

radiation resistance for, 499

time-average power radiated by, 499

Sink of charge, 157

Sink of fluid, 93

Sinusoidal steady state, traveling waves in, 429–442

Sinusoidally time varying fields:

Maxwell's equations for, 244–245

phasor representation of, 234–245

Skin depth, 472

for copper, 473

Skin effect, 473

inductance due to, 476

resistance due to, 476

Slab charge, 102

Smith chart, 445

applications of, 448–454

development of, 445–448

use as admittance chart, 451–452

Snell's law, 488

Solenoid, 147

magnetic field due to, 147–149, 173–177

Solenoidal vector, 173

Solid, crystalline, 263

Solid angle, 94, 126, 522

computation of, 212–214

unit of, 94, 522

Source distributions, analogous, 177, 179

Source of charge, 157

Source of fluid, 93

Source point–field point notation, 89, 142

Source points, 89

Space charge, in vacuum diode, 350–352

Spherical cavity:

average electric field due to \mathbf{m} in, 302–303

- Spherical cavity (*contd.*)
 average electric field due to \mathbf{p} in,
 279–280
- Spherical coordinate system:
 coordinates for, 16, 18
 curl in, 53
 differential lengths, 17, 18
 differential surfaces, 17, 18
 differential volume, 17, 18
 divergence in, 47
 gradient in, 36
 Laplacian of scalar in, 59
 Laplacian of vector in, 60
 limits of coordinates, 18
 orthogonal surfaces, 16, 18
 position vector, 17–18
 unit vectors, 17, 18
- Spin:
 electronic, 296
 nuclear, 296
- Standing wave patterns, 433
 example of determination of, 439–
 441
 for line short-circuited at both ends,
 434
 for partial standing wave, 436–439
 for short-circuited line, 433
- Standing wave ratio, voltage (*see*
 VSWR)
- Standing waves:
 complete, 432
 limitations imposed by, 443
 partial, 436
- Static electric field:
 conservative property of, 117, 178
 laws and formulas, 178
 Maxwell's equations for, 178
 realizability of, 118
- Static magnetic field:
 laws and formulas, 178
 Maxwell's equations for, 178
- T**
- Tangential component of \mathbf{E} , boundary
 condition for, 330
- Tangential component of \mathbf{H} , boundary
 condition for, 331
- Tapered transmission line, 514
- $TE_{m,0}$ modes:
 Steady state, sinusoidal (*see* Sinusoidal
 steady state)
 Stokes' theorem, 56–58
 Stream lines (*see* Direction lines)
 Stub, 443
 Stub matching, 443
 analytical solution, 443–445
 solution by Smith chart, 452–453
 Subtraction of vectors, 2–3
 parallelogram law of, 3
 Surface:
 as a vector, 13
 Gaussian (*see* Gaussian surface)
 Surface charge, 82
 electric field of, 89, 178
 polarization, 283, 284, 287, 288,
 289
 potential field of, 115, 178
 Surface charge density, 82
 polarization, 284, 286, 288
 units of, 82
 Surface current, 149
 magnetic field of, 178
 magnetic vector potential due to,
 164, 178
 magnetization, 306, 310
 Surface current density, 149
 magnetization, 308, 310
 Surface integral, 37–40
 closed, 39
 evaluation of, 39–40
 to volume integral, 48
 Surfaces:
 differential (*see* Differential surfaces)
 equipotential (*see* Equipotential sur-
 faces)
 of constant phase, 245, 415
 Susceptance, input, 453
 Susceptibility:
 electric, 281
 magnetic, 304
- $TE_{m,0}$ modes (*contd.*)
 guide impedance for, 459
 in parallel-plate waveguide, 458, 460
 transmission-line equivalent for,
 459
- $TE_{m,0,1}$ modes, 480

- TE wave, 423
 - in parallel-plate waveguide, 456
- TEM wave, 421
- TEM wave propagation, wave equation for, 421
- Test charge, 74
 - in crossed electric and magnetic fields, 194–196
 - moving, 135, 193
- Test mass, 73
- Tetrahedron, volume of, 62
- Thermal agitation, 263
- Three-dimensional representation, of traveling wave, 410
- Time-average energy density:
 - in electric field, 249, 323
 - in magnetic field, 249, 324
- Time-average power, 250
- Time-average power flow:
 - along a parallel-plate waveguide, 456
 - along a transmission line, 442
- Time-average Poynting vector, 248
 - for Hertzian dipole fields, 496
- Time constant, for decay of charge inside a conductor, 271
- Time domain, traveling waves in, 424–429
- Time-varying fields, Maxwell's equations for, 252, 317, 320–321
- TM modes, 463
- TM wave, 423
- Toroid, 188
- Toroidal conductor, 387
- Toroidal magnetic core, 388
- Torque:
 - on a current loop, 341
 - on an electric dipole, 339
- Transient waves, 428
- Transmission coefficient:
 - current, 426
 - voltage, 426
- Transmission line, 405
 - characteristic impedance of, 422
 - distributed circuit representation of, 406, 476, 477
 - lossy, 475–477
- Transmission line (*contd.*)
 - power flow along, 407
 - tapered, 514
- Transmission-line admittance (*see* Line admittance)
- Transmission-line current, notation, 423
- Transmission-line equations, 405
 - circuit representation of, 405–406
 - derivation of, 403–405
- Transmission-line equivalent, for power flow for TE waves, 459
- Transmission-line impedance (*see* Line impedance)
- Transmission-line input impedance, variation with frequency, 443
- Transmission-line matching, 442–454
 - by stub (*see* Stub matching)
- Transmission-line voltage, notation, 423
- Transmission-line waves, 422
 - analogy with uniform plane waves, 422
 - between imperfect conductors, 475–476
 - power flow associated with, 423–424
- Transmission lines, power balance at junction of, 426
- Transmitted wave, 425
- Transverse electric wave (*see* TE wave)
- Transverse electromagnetic wave, 421
- Transverse magnetic wave, 423
- Transverse plane, 421, 422
- Traveling wave:
 - three-dimensional representation of, 410
 - velocity of propagation of, 410
- Traveling waves:
 - in sinusoidal steady state, 429–442
 - in time domain, 424–429
- True charge density, 289, 311, 317
- True charges:
 - compared to polarization charges, 317
 - examples of, 317
- True current density, 289, 311, 317

- True currents:
 compared to magnetization currents,
 317
 compared to polarization currents,
 317

U

- Uniform plane wave, 412
 normal incidence on a good conductor, 472
 normal incidence on a perfect conductor, 430
 normal incidence on a perfect dielectric, 424
 oblique incidence on a perfect conductor, 454
 sinusoidally time-varying, 413
 Uniform plane wave fields:
 notation, 423
 space variation from time variation,
 412–413
 Uniform plane wave impedance (*see*
 Wave impedance)
 Uniform plane wave in three dimensions:
 apparent phase velocities, 418
 apparent wavelengths, 417
 circularly polarized, 421
 complex field vectors, 418–420
 electric field vector of, 416
 illustration of properties of, 417
 linearly polarized, 420
 magnetic field vector of, 416

V

- V (*see* Electric scalar potential)
 Vacancies, 265
 Vacuum diode:
 potential distribution in, 351–352
 simplified model of, 350
 Vector:
 area as a, 13
 curl of, 48–58
 definition of, 1
 divergence of, 44–48
 division by a scalar, 3, 20
 graphical representation of, 1
 Laplacian of, 59–60
 magnitude of, 1, 20

- True currents (*contd.*)
 examples of, 317

- Two-dimensional dipole:
 electric, 118, 125
 magnetic, 173, 185

- Uniform plane wave in three dimensions (*contd.*)

propagation vector for, 416

- Uniform plane waves, 412
 analogy with transmission-line waves, 422

power flow associated with, 412

- Uniqueness theorem, 362–363

- Unit circle, 446

- Unit conductance circle, 452

- Unit normal vector to a surface:

from cross product, 34, 35

from gradient, 35

- Unit vector, 4

from cross product, 7

- Unit vectors:

cross products of, 22

dot products of, 22

in cartesian coordinates, 11, 18

in cylindrical coordinates, 15, 18

in spherical coordinates, 17, 18

partial derivatives of, 31

- Units:

International system of, 521

MKS rationalized, 76

table of, 523–526

- Vector (*contd.*)

multiplication by a scalar, 3, 20

position (*see* Position vector)

unit (*see* Unit vector)

unique definition of, 490

- Vector addition (*see* Addition of vectors)

- Vector analysis, rules of, 1

- Vector cross product (*see* Cross product of vectors)

- Vector dot product (*see* Dot product of vectors)

- Vector fields, 27–29

- Vector identities, 56, 61, 62

- Vector notation, 1
 - Vector product (*see* Cross product of vectors)
 - Vector subtraction (*see* Subtraction of vectors)
 - Vector wave equation, 408
 - Vectors:
 - addition of, 2, 20
 - components of, 19, 25
 - cross product of, 5, 6, 20
 - differences and similarities with phasors, 239–242
 - differentiation of, 29–32
 - dot product of, 4, 20
 - equality of, 1, 20
 - examples of, 1
 - integration of, 43
 - proportionality of, 91
 - scalar triple product of, 7, 21
 - subtraction of, 2, 3
 - unit (*see* Unit vectors)
 - Velocity:
 - drift, 265, 266, 267
 - group (*see* Group velocity)
 - phase (*see* Phase velocity)
 - Velocity of light, in free space, 140
 - Velocity of propagation, of traveling wave, 410
 - Volt, definition of, 105, 522
- W**
- Watt, definition of, 522
 - Wave:
 - incident, 425
 - reflected, 425
 - TE (*see* TE wave)
 - TEM, 421
 - TM, 423
 - transmitted, 425
 - Wave equation:
 - for a plasma medium, 485
 - for TEM wave propagation, 421
 - scalar (*see* Scalar wave equation)
 - vector, 408
 - Wave equations:
 - inhomogeneous, 490
 - scalar, 408–409
 - Wave impedance, 434; *see also* Line impedance
 - Voltage:
 - compared to potential difference, 202
 - induced, 197
 - Voltage reflection coefficient, 426
 - Voltage standing wave ratio:
 - definition of, 438
 - from the Smith chart, 450
 - Voltage transmission coefficient, 426
 - Volume, differential (*see* Differential volume)
 - Volume charge, 82
 - electric field of, 89, 178
 - potential field of, 115, 178
 - spherical, 83
 - Volume charge density, 82
 - polarization, 286
 - units of, 82
 - Volume current, 149
 - magnetic field of, 178
 - magnetic vector potential due to, 164, 178
 - Volume current density, 149
 - magnetization, 308, 310
 - polarization, 285, 288
 - Volume integral, 36–37
 - evaluation of, 37
 - VSWR (*see* Voltage standing wave ratio)
 - Wave impedance (*contd.*)
 - for normal incidence on perfect conductor, 434
 - for partial standing wave, 436
 - for TE waves in parallel-plate waveguide, 459
 - Wave propagation:
 - in good conductor, 472
 - in lossy media, 468
 - in perfect dielectric, 408
 - in plasma, 484
 - Waveguide:
 - parallel-plate (*see* Parallel-plate waveguide)
 - rectangular (*see* Rectangular waveguide)
 - Wavelength:
 - apparent, 417

Wavelength (*contd.*)

- definition of, 413
- guide, 458
- times frequency, 414

Waves:

- Electromagnetic (*see* Electromagnetic waves)
- Standing (*see* Standing waves)
- Transient, 428
- Transmission-line (*see* Transmission-

Waves (*contd.*)

- line waves)
 - Traveling (*see* Traveling waves)
- Work, 104, 117
 - for assembling a solenoidal current distribution, 226–228
 - for assembling a system of point charges, 221–223
 - in displacing a charge, 230